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BOOK REVIEW

Proceedings of the Workshop on Standard Model Physics (And More) at the LHC

(CERN Report 2000-004)
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The Large Hadron Collider, LHC, is expected to be operational in 2005. It is a proton-on-proton collider with centre-of-mass energy of 14 trillion electron volts, TeV. It will also have the possibility of heavy ion, lead-on-lead, collisions. Particles with masses upto 5 TeV are going to be accessible. The lower mass objects, such as the bottom (denoted b) and the top (t) quarks, the W and the Z bosons, are going to be produced copiously. In addition, there is the chance that the Higgs boson may be detected. The LHC pushes the standard model, SM, to its limits. The Cern Report 2000–004 is a thorough and a detailed account of the events the LHC is going to explore, and documents the expectations from the SM.

The report, 530 pages long, is divided into 5 parts. The first part, Quantum Chromodynamics, QCD, takes 116 pages. Electroweak physics, the next section, runs to 114 pages. The bottom quark production is taken up in the next 75 pages. The following 110 pages are devoted to the decay of the bottom quark. The final section, 110 pages long, is on the physics of the top quark. Each part has several authors. We give below a brief outline of the five parts.

The First Part : QCD

The first section, QCD, is of importance as at the energies being considered particle searches and precision measurements are subject to the effects of quark-glue strong interactions. An understanding of QCD ; its implementation in Monte Carlo, MC, is a prerequisite.

The parton distributions have to be clearly understood. The quark-antiquark distributions come from deep-inelastic lepton-hadron scattering and the Drell – Yan lepton – pair production in hadron collisions. The gluon distributions come from hadron-hadron processes with photons in the final state. At present there are a number of parton distribution models of varying uncertainties. They form the basis for prediction of the cross sections. Towards LHC, new and quantitative methods are being developed.

The parton collisions are modelled from QCD. These MC programs are divided into three parts : 1. the hard scattering, 2. the parton showers and 3. hadronisation. The MC generators for the three parts have to be properly matched. The effect of higher order QCD corrections are needed for accurate prediction. Next to leading order calculations exist for hadron/partial hadrons in the final state. The QCD dynamics in the region of small x is reviewed at length. There are many cases with two large and different scales. These have large log corrections. The method, due to Balitsky – Fadin – Kuraev – Lipatov (BFKL) to take care of these cases, however, does not give satisfactory account at present. The subleading and next-to-leading corrections are needed.

Another important aspect is the simultaneous occurrence of two or more independent hard parton scattering in the same interaction. Experience with the Fermilab Tevatron suggests this could be important at the LHC.

The QCD section concludes with a detailed account of the background for Higgs searches for final states with the photons or many leptons.

The Second Part : Electroweak Physics

Electroweak physics at the LHC has four main parts. 1) Precise determination of eletroweak parameters and the masses ; 2) The triple gauge vector coupling in relation to next-to-leading order QCD calculations on productions of W^+W^-, $W^\pm Z$, ZZ, $W^\pm\gamma$ and $Z\gamma$; 3) Direct measurement of triple and quartic gauge vector coupling and 4) Gauge vector scattering at high energies.

The precision electroweak parameters of interest are the mixing angles, masses of the top and the W, vector boson self-couplings and the mass of the Higgs boson. Good measurements of these quantities can detect deviations from the SM. The top mass contributes to the determination of parameters. For instance, the deviation $\Delta\rho$ of the parameter ρ from unity goes us :

$$\Delta\rho = \frac{3G_\mu m_t^2}{8\Pi^2\sqrt{2}} . \quad (1)$$

Here, the b mass is assumed negligible.

Once again, the effect of the t mass and the Higgs mass appear in the precise determination of the W mass :

$$M_W = \sqrt{\frac{\Pi\alpha}{G_F\sqrt{2}}} \frac{1}{\sin\theta_u} \frac{1}{} \quad (2)$$

Here, Δr is a measure of the radiative loop effects and are estimated at 4%. The radiative corrections go as m_t^2 and $\log m_H$ The precise measurements of M_W and m_t places constraints on m_H. From LEP2 and Tevatron M_W is known to within 30 MeV. It is hoped the masses of m_t and M_W will be determined to an accuracy that the Higgs mass is determined to within 30%. The candidate theories that extend SM may be distinguished / eliminated from these precise measurements.

Production of gauge boson pairs tests the nonabelian nature of the underlying theories. If the Higgs is heavy, it decays to W^+W^- and ZZ. For minimal supersymmetric extensions small anomalous couplings at low energies appear. For dynamic symmetry breaking models, such as technicolour or BESS, large anomalous couplings, or new heavy particles appear. Interestingly the pair production of vector bosons is the background to new physics. Supersymmetry signal, for example, is three charged leptons and missing momentum. The background here is WZ or W_γ.

Consistent with Lorentz invariance the three gauge vector vertices of WWZ and WW_γ can have 14 independent possibilities. The changes to the SM are, however, fairly constrained. Simple additions of gauge groups/ fermions do not change the SM results significantly as these contribute through radiative effects. Removing Higgs makes the theory nonrenormalisable and cut-off dependent. An even severe change is to assume the 14 couplings mentioned above are different. These issues are tested in measurements of triple vector couplings. It is of interest to note that the possible independent quartic couplings of the vector bosons $WW_{\gamma\gamma}$, $Z_\gamma WW$, $ZZWW$ and $WWWW$ have 34, 54, 81, and 81 possibilities!

The Third Part : Bottom Quark Production

A large number of b-quarks are going to be produced at the LHC. Study of b-production serves as a test for QCD. In many other experiments b is in the background. It is, therefore, essential to understand bottom quarks production at the LHC.

At the UA1 experiment, the b was first observed. Subsequently, it has been studied at the Tevatron. The correlations between productions of b and anti-b, the transverse momentum spectra are by now well studied. The present status is one of mixed success. The shape of the correlations and b-distributions are fairly well understood from perturbative QCD ; yet the observed cross sections are larger than QCD predictions. At the LHC, this anomaly has to be resolved. It is possible that the effects of the higher orders are more, or that there are significant nonperturbative effects. Some of these nonperturbative possibilities, amongst them fragmentation, are studied in MC models of hadronisation in this review.

Another topic of current interest is the charge asymmetry in b production in pp colliders. QCD perturbative scheme predicts a small value. Thus the hadronisation models are studied to understand the effects. The underlying nonperturbative physics is reviewed as well as its implications for CP violations in the decay of B.

The production of quarkonium is of interest because many of these rates are way larger than the theoretical estimates. These are, again, ascribed to nonperturbative effects. In recent years, a new approach, called nonrelativistic QCD, has emerged to account for the discrepancies in quarkonium production.

This part concludes with detailed discussion of the prospects of b detection followed by a review of the MC package PYTHIA for heavy flavour events.

The Fourth Part : B Decays

The LHC production cross section for $b\bar{b}$ is high, a factor of five higher than at Tevatron. The machine parameters are optimised for B physics. *CP* violation remains an intriguing problem. While K and D have provided some of the insights, the most thorough quantitative understanding is going to come from the B system. While the CKM matrix has all the angles and the phases, the parametrisation of Wolfenstein has been widely used. It is written in powers of the small quantity $\sin\theta_c$. The experimental accuracy in the LHC era requires next-to-leading orders in expansion in terms of this small parameter. The nonleptonic decay modes of B involve tree and the penguin contributions. The penguins in turn are from the glue and the electroweak. $B-\bar{B}$ mixing, neutral B decays, the B_s system and charged B decays all provide data for the determination of the parameters of the unitarity triangle of the CKM matrix.

The rare B decays are the ones that are cabibbo suppressed ($b \to u$), or the ones suppressed due to flavour changing neutral currents FCNC. The FCNC decays directly measure the CKM elements $|V_{ts}|$ and $|V_{td}|$ which are responsible for $B_0 - \bar{B}_0$ mixing.

The experimental environment in hadron machines makes it difficult to study inclusive decays : the exclusive ones are preferred. However, the exclusive ones have uncontrolled, large, nonperturbative QCD corrections. The recent QCD calculations have reduced the uncertainties. In this context, the following exclusive processes are discussed : $B_{d,s} \to \mu^+\mu^-$, $B_d \to K^*\gamma$ and $B_d \to K^*\mu^+\mu^-$. Interestingly, there are experimental possibilities where the theoretical uncertainties cancel.

The Fifth Part : Top Quark Physics

The tevatron produced small numbers of top quark. The t mass, its production cross section, its tau – lepton decay mode, search for FCNC decays, W helicity in t-decay have been studied on small samples. The LHC is going to produce t in large amounts, about 8 million $t\bar{t}$ pairs per experiment per year plus another few million single t or $\bar{t}$ through electroweak processes. The LHC enhances the precision on t related measurements. It also opens up possibilities of new measurements.

The t-quark, produced in colliders, decays rapidly into $W + b$ without producing hadrons. The rare decays and CP violation are extremely small. The unitarity requirement completely determines the CKM element V_{tb}. In a sense the t-quark physics looks uninteresting.

However, the t mass being heavy presents *a* rare opportunity. It is curiously close to the electroweak breaking scale. If this mass is generated through the usual Higgs -Yukawa route, the corresponding coupling is large. It is possible that new physics beyond the SM manifests at the t-quark level. Does the t play any role in electroweak breaking ?

The results of SM calculations of the t mass ; its decay width are documented. The dominant decay mode is into $W + b$. The results documented pertain to this mode. The production cross section of $t\bar{t}$, the transverse momentum and the $t\bar{t}$ invariant mass distributions are reviewed next. The electroweak radiative corrections and the radiative effects from the minimal supersymmetric standard model, MSSM, are discussed.

The key issues in the measurement of the t mass are discussed next. The large transverse momenta in leptons + jets and measurements of the correlations in t decaying to lepton $+ J/\psi + X$ are promising. The systematic uncertainties in these are laid out in detail. To probe the t-charged current and to access the CKM element V_{tb} it is necessary to measure single t productions *via* electroweak effects. The SM estimates of three t production mechanisms are discussed.

The spin correlations in $t\bar{t}$ production is analysed in depth, next. The anomalous spin-momentum correlations are related to nonstandard CP violating scenarios. These interrelations are documented. The SM expectations on radiative t decays and FCNC decays are laid out. In this context, the two Higgs doublet model, MSSM and other anomalous coupling possibilities are discussed in detail. The ATLAS and CMS studies on the sensitivity in specific channels are reviewed.

The $t\,t$ H production *via* Yukawa coupling is the final topic. The SM cross sections are documented. Assuming the Higgs to be of a relatively low mass a realistic simulation of the ATLAS detector is detailed.

The present decade and more in high energy physics is going to be dominated by the LHC. To a considerable extent it is going to decide what is investment grade. Decades of speculative activity are going to be set to rest ; new leads are going to emerge. For the serious physicist, every beat of the LHC is of utmost importance. For all of them, the CERN report 2000-004 is a must.

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